Technology Matters

Questions to Live With

David E. Nye

The MIT Press
Cambridge, Massachusetts
London, England

MIT Press books may be purchased at special quantity discounts for business or sales promotional use. For information, please email special_sales@mitpress.mit.edu or write to Special Sales Department, The MIT Press, 55 Hayward Street, Cambridge, MA 02142.

Set in Stone Sans and Stone Serif by Graphic Composition, Inc.
Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Nye, David E., 1946–
Technology matters: questions to live with / David E. Nye
p. cm.
Includes bibliographical references and index.
ISBN 0-262-14093-4
1. Technology—Philosophy. 2. Technology and civilization. I. Title.
T14.N88 2006 303.48'3—dc22 2005052114

10 9 8 7 6 5 4 3 2 1

2 Does Technology Control Us?

Are technologies deterministic?[1] Many people talk as though they are. Students have often told me that the spread of television or the Internet was "inevitable." Likewise, most people find the idea of a modern world without automobiles unimaginable. However, history provides some interesting counterexamples to apparently inevitable technologies. The gun would appear to be the classic case of a weapon that no society could reject once it had been introduced. Yet the Japanese did just that. They adopted guns from Portuguese traders in 1543, learned how to make them, and gradually gave up the bow and the sword. As early as 1575 guns proved decisive in a major battle (Nagoshino), but then the Japanese abandoned them, for what can only be considered cultural reasons. The guns they produced worked well, but they had little symbolic value to warriors, who preferred traditional weapons.[2] The government restricted gun production, but this alone would not be enough to explain Japan's reversion to swords and arrows. Other governments have attempted to restrict gun ownership and use, often with little success. But the Japanese samurai class rejected the new weapon, and the gun disappeared. It re-entered society only after 1853, when Commodore Perry sailed his warships into Japanese waters and forced the country to open itself to the West.

Japan's long, successful rejection of guns is revealing. A society or a group that is able to act without outside interference can abolish a powerful technology. In the United States, the Mennonites and the Amish do not permit any device to be used before they have carefully evaluated its potential impact on the community. For example, they generally resist home telephones and prefer face-to-face communication, although they permit limited use of phones to deal with the outside world. They reject both automobiles and gasoline tractors. Instead, they breed horses and build their own buggies and farm machinery. These choices make the community far more self-sufficient than it would be if each farmer annually spent thousands of dollars on farm machinery, gasoline, and artificial fertilizer, all of which would necessarily come from outside the community. Their leaders decide such matters, rather than leaving each individual to choose in the market. Such practices might seem merely quaint, but they provide a buffer against such things as genetically modified foods or chemical pesticides, and they help to preserve the community. Indeed, the Amish are growing and flourishing. Both the Japanese rejection of the gun and the Amish selective acceptance of modern farming equipment show that communities can make self-conscious technological choices and can resist even very powerful technologies.

Furthermore, these two examples suggest that the belief in determinism paradoxically seems to require a "free market." The belief in technological determinism is widely accepted in individualistic societies that embrace laissez-faire economics. What many people have in mind when they say that television or the Internet was "inevitable" boils down to an assumption that these technologies are so appealing that most consumers, given the chance, will buy them. Historians of technology often reject this view because they are concerned not only with consumers but also with inventors, entrepreneurs, and marketers. They see each new technology not simply as a product to be purchased, but as a part of a larger system. Few historians argue that machines determine history. Instead, they contend that new technologies are shaped by social conditions, prices, traditions, popular attitudes, interest groups, class differences, and government policy.[3]

A surprising number of people, however, including many scholars, speak and write about technologies as though they were deterministic. According to one widely read book, television has "helped change the deferential Negro into the proud Black," has "given women an outside view of their incarceration in the home," and has "weakened visible authorities by destroying the distance and mystery that once enhanced their aura and prestige."[4] These examples suggest that technology has an inexorable logic, that it forces change. But is this the inexorable effect of introducing television into China or the Arab world? In some cases, one might argue, television is strengthening fundamentalism. It simply will not do to assume that the peculiar structure of the American television market is natural. In the United States, television is secular, not religious; private, not public; funded by advertising, not taxation; and a conduit primarily of entertainment, not education. These are cultural choices.

Many have made a similar mistake in writing about the Internet. Nicholas Negroponte declared, in a best-selling book, that "digital technology can be a natural force drawing people into greater world harmony."[5] This is nonsense. No technology is, has been, or will be a "natural force." Nor will any technology by itself break down cultural barriers and bring world peace. Consider the wheel, an invention that most people think of as essential to civilization. Surely the wheel must be an irresistible force, even if the gun and the automobile are not! Much of North Africa, however, let the wheel fall into disuse after the third century A.D., preferring to transport goods by camel. This was a sensible choice. Maintaining roads for wheeled carts and supplying watering sites for horses and oxen was far more expensive, given the terrain and the climate, than opting for the camel, which "can carry more, move faster, and travel further, on less food and water, than an ox," needs "neither roads nor bridges," and is able to "traverse rough ground and ford rivers and streams."[6] In short, societies that have used the wheel may turn away from it. Other civilizations, notably the Mayans and the Aztecs, knew of the wheel but never developed it for practical purposes. They put wheels on toys and ceremonial objects, yet apparently they did not use wheels in construction or transportation. In short, awareness of particular tools or machines does not automatically force a society to adopt them or to keep them.

In *Capitalism and Material Life,* Fernand Braudel rejected technological determinism. Reflecting on how slowly some societies adopt new methods and techniques, he declared: "Technology is only an instrument and man does not always know how to use it."[7] Like Braudel, most specialists in the history of technology do not see new machines as coercive agents dictating social change, and most remain unpersuaded by determinism, though they readily agree that people are often reluctant to give up conveniences. For millennia people lived without electric light or central heating, but during the last 150 years many societies have adopted these technologies and made them part of their building codes. It is now illegal in many places to build or live in a house without indoor plumbing, heating, and electric lighting. In other words, people become enmeshed in a web of technical choices made for them by their ancestors. This is not determinism, though it does suggest why people may come to feel trapped by choices others have made.

Often, adopting a new technology has unintended consequences. Governments build highways to relieve traffic congestion, but better roads may attract more traffic and reduce the use of mass transit as an alternative. Edward Tenner, in his book *Why Things Bite Back,* examines "the revenge of unintended consequences."[8] Among many examples, he notes that computers are expected to improve office efficiency, but in practice people spend enormous amounts of time adjusting to updated software and they suffer eyestrain, back problems, tendonitis, and cumulative trauma disorder.[9] Furthermore, to the extent that computers replace secretaries, white-collar professionals often find themselves doing routine tasks, such as copying and filing documents and stuffing envelopes. Thus, despite many claims made for greater efficiency through computerization, a study by the American Manufacturing Association found that reducing staff raised profits for only 43 percent of the firms that tried it, and 24 percent actually suffered losses, despite the savings on wages. In some cases computerization reduced the time that highly skilled employees had available to perform skilled work. "Their jobs became more diverse in a negative way, including things like printing out letters that their secretaries once did."[10] For some white-collar workers, the computer had the unintended consequence of diminishing their specialization.

In short, rather than assuming that technologies are deterministic, it appears more reasonable to assume that cultural choices shape their uses. While salesmen and promoters like to claim that a new machine is inevitable and urge us to buy it now or risk falling behind competitors, historical experience strongly suggests that the actual usefulness of a new technology is unpredictable.

The idea that mechanical systems are deterministic remains so persistent, however, that a brief review of this tradition is necessary. In the middle of the nineteenth century, most European and American observers saw machines as the motor of change that pushed society toward the future. The phrase "industrial revolution," which gradually came into use after c. 1875, likewise expressed the notion that new technologies were breaking decisively with the past. Early socialists and free-market capitalists agreed on little else, but both saw industrialization as an unfolding of rationality. Even harsh early critics tended to assume that the machine itself was neutral, and focused their attacks on people who misused it. Not until the twentieth century did many argue that technologies might be out of control or inherently dangerous. Technological determinism, which in the nineteenth century often seemed beneficent, appeared more threatening thereafter.

Some Victorians worried that machinery seemed to proliferate more rapidly than the political means to govern it. Without any need of the word "technology," Thomas Carlyle issued a full-scale indictment of industrialization that contained many of the negative meanings that later would be poured into the term. His contemporary Karl Marx saw the mechanization of society as part of an iron law of inevitable historical development.[11] In *The Critique of Political Economy,* Marx argued that "the mode of production of material life determines the general character of the social, political, and spiritual process of life."[12] (Marx did not use the word "technology" in the first edition of *Das Kapital,*[13] though it did appear in later editions. His collaborator, Engels, took up the term "technics" late in life.[14]) Marx argued that industrialization's immediate results were largely negative for the working class. The skilled artisan who once had the satisfaction of making a finished product was subjected to the subdivision of labor. The worker, who once had decided when to work and when to take breaks, lost control of such choices in the new factories. Capital's increasing control of the means of production went along with de-skilling of work and lowering of wages. Industrialization broke the bonds of communities and widened the gaps between social classes. Marx argued that capitalism would collapse not only because it was unjust and immoral, and not only because poverty and inequality would goad the workers to revolt, but also because it would create economic crises of increasing intensity. These crises were not caused by greed or oppression, and they would occur no matter how well meaning capitalists themselves might be. For Marx, the logic of capitalism led to continual investment in better machines and factories, which tied up resources in "fixed capital," leaving less money available for wages ("variable capital"). As investments shifted from labor power to machinery, the amount available for wages and the number of workers employed had to decrease; otherwise the capitalist could not make a profit. This made sense for each individual capitalist, but the overall effect on society when many factories cut total wages and substituted machines for men was a decrease in demand. At the very time when a capitalist had more goods to sell (because he had a new and better production system), fewer people had money to purchase those goods. Thus, Marx argued, efficiency in production flooded the market with goods, but simultaneously the substitution of machines for laborers undermined demand. A crisis was unavoidable. If a capitalist halted production until he had sold off surpluses, he reduced demand still further. If he raised wages to stimulate demand, profits fell. If he sought still greater efficiencies through mergers with rivals, he threw even more workers on the dole, and the imbalance between excessive supply and weak demand became more severe. Marx's analysis posited the inevitable end of capitalism. As greater mechanization produced greater surpluses, it impoverished more workers, causing increasingly severe economic crises because supplies outran demand. Mechanization under capitalism apparently led unavoidably to worker exploitation, social inequality, class warfare, social collapse, and finally revolution.

Marx did not reject technology itself. After the collapse of capitalism, he expected, a succeeding socialist regime would appropriate the means of production and build an egalitarian life of plenty for all. If Marxism made a powerful critique of industrialization that included such concepts as class struggle, worker alienation, de-skilling of artisans, false consciousness, and reification, ultimately it was not hostile to the machine as such. Rather, both Marx and Engels expected that industrialization would provide the basis for a better world. Similarly, Lenin hoped that after the Russian Revolution the technical elite would rationally direct further industrialization and redistribute the wealth it produced. Lenin argued that revolutionary change "should not be confused with the question of the scientifically trained staff of engineers, agronomists and so on." "These gentlemen," he continued, "are working today in obedience to the wishes of the capitalists, and will work even better tomorrow in obedience to the wishes of the armed workers."[15] After the Revolution, the Soviet Union emphasized electrification and mass production. Lenin famously declared that only when the Soviet Union had been completely electrified could it attain full socialism. He vigorously pursued a ten-year plan of building generating plants and incorporated them into a national grid, with the goal of extending electrical service to every home.[16] As this example suggests, Marxists criticized how capitalists used technical systems but not industrialization itself.

The left generally assumed that a society's technologies defined its economic system and social organization. Thus the primitive mill produced feudalism, while the steam engine produced capitalism. They equated mechanization and industrialization with the rational unfolding of history. Evolutionary socialists agreed that technological systems ultimately would become the basis of a utopia, without, however, expecting that violent class conflict and revolution were necessary to attain it. They believed that new technologies would lead to the inevitable decline of capitalism and the emergence of a better economic system. For example, German-born Charles Steinmetz, the leading scientist at General Electric in its first decades, expected socialism to emerge along with a national electrical grid, because it was an inherently interdependent basis for economic reorganization. Electricity could not be stored efficiently and had to be consumed through large distribution systems as soon as it was produced. "The relation between the steam engine as a source of power and the electric motor is thus about the same as the relation between the individualist [capitalist] and the socialist. . . . The one is independent of everything else, is self-contained, the other, the electric motor, is dependent on every other user in the system. . . . The electric power is probably today the most powerful force tending towards co-ordination, that is cooperation [socialism]."[17] Both Marxists and evolutionary socialists embraced not only the machine but also a sense of inevitable historical development based on technological change.

In contrast, Werner Sombart rejected such determinism in *Technik und Kultur,* where he argued that cultures often shaped events more than technologies did. For example, Sombart thought that the failure of cultural and political institutions, and not technological change, accounted for the decline of ancient Rome. Sombart accorded technology an important role in history, particularly in modern times, but he also recognized the importance of culture and institutions. The Chicago School of sociology developed Sombart's ideas in the United States. For example, when William Ogburn wrote about "the influence of invention and discovery," he denied that "mechanical invention is the source of all change" and pointed to "social inventions" such as "the city manager form of government . . . which have had great effects upon social customs. While many social inventions are only remotely connected with mechanical inventions, others appear to be precipitated by" them, such as "the trade union and the tourist camp." Influence could flow in either direction. Social inventions could stimulate technical invention.[18] Ogburn admitted that mechanization had a powerful effect on society, yet he emphasized that "a social change is seldom the result of a single invention." Women's suffrage, for example, was the outcome of a great number of converging forces and influences, including mass production, urbanization, birth control, the adoption of the typewriter, improved education, and the theory of natural rights. Most historical changes were attributable to such a "piling up process." Making the distinction between social invention and technical invention also suggested to Ogburn the notion of a cultural lag. "There is often a delay or lag in the adaptive culture after the material culture has changed, and sometimes these lags are very costly, as was the case with workmen's compensation for industrial accidents."[19] "The more one studies the relationship between mechanical and social inventions," Ogburn concluded, "the more interrelated they seem. Civilization is a complex of interconnections between social institutions and customs on the one hand, and technology and science on the other."[20] Because "the whole interconnected mass is in motion,"[21] it was difficult to establish causation.

The idea that technologies developed more rapidly than society remained attractive to some later theorists. During the 1960s, Marshall McLuhan won a large following as he argued that every major form of communication had reshaped the way people saw their world, causing changes in both public behavior and political institutions. For McLuhan, innovations in communications, notably the printing press, radio, and television, had automatic effects on society. Unlike Ogburn, McLuhan paid little attention to reciprocal effects or social inventions. For McLuhan, not only did the media extend the human sense organs; each new form of a medium disrupted the relationship between the senses. McLuhan argued that the phonetic alphabet intensified the visual function and that literate cultures devalued the other senses—a process that moveable type intensified. Furthermore, McLuhan thought electronic media extended the central nervous system and linked humanity together in a global network. Alvin Toffler reworked such deterministic ideas into *Future Shock,* a best-seller that argued that technological change had accelerated to the point that people scarcely could cope with it. Later, in *The Third Wave,* Toffler argued that a new industrial revolution was being driven by electronics, computers, and the space program.[22] In such studies, the word "impact" suggests that machines inexorably impress change on society.

Although the details of their analyses varied, both McLuhan's arguments and Toffler's were *externalist,* treating new technologies as autonomous forces that compel society to change. The public has an appetite for proclamations that new technologies have beneficent "natural" effects with little government intervention or public planning. Externalist arguments attribute to a technology a dominant place within society, without focusing much on invention or technical details. Externalist studies of "technology transfer" often say little about machines and processes, such as firearms or textile factories, but a great deal about their "impact" on other countries.[23] Externalists usually adopt the point of view of a third-person narrator who stands outside technical processes. They seldom dwell on the (often protracted) difficulties in defining the technological object at the time of its invention and early diffusion. Close analysis—common in the internalist approach to be described in chapter 4—tends to undermine determinism, because it reveals the importance of particular individuals, accidents, chance, and local circumstances.

Determinism is not limited to optimists. Between 1945 and 1970, many of the most pessimistic critics of technology were also determinists. Jacques Ellul paid little attention to the origins of individual inventions, but argued instead that an abstract "Technique" had permeated all aspects of society and had become the new "milieu" that Western societies substituted for Nature. Readers of Ellul's book *The Technological Society*[24] were told that Technique was an autonomous and unrelenting substitution of means for ends. Modern society's vast ensemble of techniques had become self-engendering and had accelerated out of humanity's control: "Technical progress tends to act, not according to an arithmetic, but according to a geometric progression."[25]

Writers on the left found technology equally threatening, and many thought the only possible antidote to be a dramatic shift in consciousness. In *One-Dimensional Man* (1964) and other works, Herbert Marcuse, a Marxist sociologist whose work emerged from the Frankfurt School, attacked the technocratic state in both its capitalist and its socialist formations. He called for "revolutionary consciousness-raising" in preparation for a wholesale rejection of the managed system that everywhere was reducing people to unimaginative cogs in the machine of the state. Marcuse, who became popular with the student movements of the late 1960s, hoped that the "New Left" would spearhead the rejection of the technocratic regime. In *The Making of a Counter Culture* (1969), Theodore Roszak was equally critical but less confrontational, arguing that reform of the technocratic state was impossible. His first chapter, "Technocracy's Children," attacked the mystification of all decision making as it became clothed in the apparently irrefutable statistics and the terminology of technocrats. Western society had become a "technocracy," defined by Roszak as "that society in which those who govern justify themselves by appeal to technical experts who, in turn, justify themselves by appeal to scientific forms of knowledge."[26] Such a technical ideology seemed "ideologically invisible" because its assumed ideals—rationality and efficiency—were accepted without discussion both in the communist East and the capitalist West. To resist technocracy, a de-technologized consciousness was needed, which Roszak sought through a combination of Zen Buddhism, post-Freudian psychology, and the construction of alternative grassroots institutions, such as those in the emerging hippie movement.[27]

As student radicalism faded during the 1970s, social revolution seemed less probable than technological domination, notably as analyzed in the work of Michel Foucault. He treated technology as the material expression of an overarching discourse that structured individual consciousness and shaped institutions, notably hospitals, asylums, and prisons.[28] In contrast to Marx, Foucault's theory did not conceive of an economic or a technical "base" that drove changes in the social "superstructure." Rather, Foucault saw history as the exfoliation of patterns of ideas and structures ("epistemes"), which were expressed in art, in architecture, in classification systems, in social relations, and in all other aspects of the cultural discourse at a given historical moment. The epistemes did not evolve from one discursive system to the next but rather were separated by ruptures, or breaks in continuity. When a new discourse emerged, it did not build upon previous systems. Rather, as a sympathetic critic summarized, "a new knowledge begins, it is unrelated to previous knowledge."[29] Foucault conceived history as a series of internally coherent epistemological systems, each built upon different premises. The individual author, inventor, or citizen was not the master of his or her fate but rather was penetrated and defined by discourses. Each was caught within, scarcely aware of, and ultimately articulated by structures of knowledge and power that were deployed and naturalized throughout society. In the modern episteme, Foucault was concerned with how power became anonymous and embedded in bureaucracies, making hierarchical surveillance a social norm. His determinism was far more comprehensive than that of most previous thinkers.

Foucault, and later the postmodernist Francois Lyotard, authored academic best-sellers of the 1970s and the 1980s, but their grand deterministic theories found little favor among historians of technology, whose research showed considerable evidence of human agency in the creation, dissemination, and use of new technologies. Leo Marx declared that postmodern theorists in effect ratify "the idea of the domination of life by large technological systems" and promote a "shrunken sense of human agency."[30] The most sweeping rejection of technological determinism came from Marx's student Langdon Winner in *Autonomous Technology,* a book Winner said he had written in a spirit of "epistemological Luddism."[31] In dismantling deterministic ideologies, Winner made it easier to think of technologies as socially shaped, or constructed. Winner also emphasized Karl Marx's more flexible views of technology in his earlier works. In

The German Ideology (1846), Winner comments, "human beings do not stand at the mercy of a great deterministic punch press that cranks out precisely tailored persons at a certain rate during a given historical period. Instead, the situation Marx describes is one in which individuals are actively involved in the daily creation and recreation, production and reproduction of the world in which they live."[32] While Marx's labor theory of value might seem to suggest rigid determinism, Winner argues that his work as a whole does not support such a view.

Technological determinism lacks a coherent philosophical tradition, although it remains popular. A variety of thinkers on both the right and the left have put forward theories of technological determinism, but the majority of historians of technology have not found them useful. As the following two chapters will show, deterministic conceptions of technology seem misguided when one looks closely at the invention, the development, and the marketing of individual devices.

3 Is Technology Predictable?

If technologies are not deterministic, then neither their emergence nor their social effects should be predictable. To consider this proposition in detail, we can divide technological prognostication into three parts: prediction, forecasting, and projection. We predict the unknown, forecast possibilities, and project probabilities. These three terms correspond to the division common in business studies of innovation, between what James Utterbeck terms "*invention* (ideas or concepts for new products and processes), *innovation* (reduction of an idea to the first use or sale) and *diffusion* of technologies (their widespread use in the market)."[1]

Prediction concerns inventions that are fundamentally new devices. This is a more restrictive definition than the US Patent Office's sense of "invention," for that also includes "innovation," treated here as a separate category. What is the distinction? The incandescent electric light was an invention; new kinds of filaments were innovations. The telephone was an invention, but the successive improvements in its operation were innovations. Inventions are fundamental breakthroughs, and there have been relatively few. In communications, they would include the telephone, the electric light, radio, television, the mainframe computer, the personal computer, and the Internet. While prediction

Table 3.1

Form of prognostication	Persons typically involved	Their focus	Their time frame
Prediction	Inventors, utopian writers	Breakthrough inventions	Long term
Forecasting	Engineers, entrepreneurs	Innovations	Less than 10 years
Projection	Designers, marketers	New models	Less than 3 years

concerns such inventions, forecasting concerns innovations, which are far more numerous. Innovations are improvements and accessories to systems that emerged from inventions. The third term, "projection," which I will discuss only briefly, concerns the future sales, profits, market share, and so forth of new models of established technologies.

Prediction, forecasting, and projection typically involve different professionals working within different time frames. (See table 3.1.) These distinctions are not merely a matter of semantic convenience. If one looks at the time frames involved, prediction deals with the long term or even indefinite periods, whereas forecasting focuses on immediate choices about getting a new device perfected and into production. Those making projections must work within the shortest time frame, because they deal with new (often annual) models of devices that compete in the market.

Who is centrally involved in prognostication depends on which category one is dealing with. Inventors, futurologists, and some academics predict or debunk the possibility of fundamental breakthroughs. Once a workable device exists, however, venture capitalists, engineers, and consultants busy themselves with forecasting its possibilities. If a device is widely accepted, designers and marketers take a central role in projecting and extrapolating what new styles and models consumers will buy. In view of the differences in actors and in time frames, there are considerable differences in the aesthetics of invention, innovation, and product development, emphasizing, respectively, technical elegance, functionalism, and beauty.[2]

On television one mostly hears forecasting and projection, not prediction. For example, in 1998 a “technology guru” on the Cable News Network announced that voice recognition would be the “next big thing” in computers because keyboards could then be done away with, and small computers capable of responding to verbal commands would be embedded in useful objects everywhere.[3] Machine speech recognition was already used by telephone companies by that time; its possible extension and development to replace computer keyboards was forecast. Eight years later, voice recognition seems to have spread more slowly than that “guru” expected.

All technological predictions and forecasts are in essence little narratives about the future. They are not full-scale narratives of utopia, but they are usually presented as stories about a better world to come. The most successful present an innovation as not just desirable but inevitable. Public-relations people are well aware that such stories can become self-fulfilling when investors and consumers believe them. As the consultant and critic John Perry Barlow once put it, “the best way to invent the future is to predict it—if you can get enough people to believe your prediction, that is.”[4]

Selling stories of the wonders to come has been popular at least since the Chicago World’s Columbian Exposition of 1893,[5] and they have become the stock in trade of investment newsletters, some technical magazines, and certain educational television programs. To put this another way, inventors and corporate research departments create not only products but also compelling narratives about how these new devices will fit into everyday life. They need to do this to get venture capital, and companies need to market such scenarios to get a return on investment.

Yet accurate prediction is difficult, even for experts. George Wise, a historian who worked for years at the General Electric research labs in Schenectady, wrote his doctoral thesis on how well scientists, inventors, and sociologists predicted the future between 1890 and 1940. Examining 1,500 published predictions, he found that only one-third proved correct, while one-third were wrong and another one-third were still unproved. They used many methods, including intuition, analogy, extrapolation, studying leading indicators, and deduction, but all were of roughly equal accuracy.[6] The technical experts, he found, performed only slightly better than others. In short, technological predictions, whoever made them and whatever method was employed, proved no more accurate than flipping a coin.

If prediction has proved extremely difficult, what about forecasting? That ought to be easier, because it deals with already invented technologies and builds on existing trends. Anyone interested in computers has heard of Moore's Law, formulated in 1965, which predicted, quite accurately, that computer memory would double roughly every 18 to 24 months.[7] (Note, however, that this may have been a self-fulfilling prophecy, because it established a benchmark for development in the computer industry.) Yet for every such success there are famous failures of forecasting. No demographer saw the United States' post-World War II baby boom coming. American birth rates had fallen steadily for more than 100 years, and demographers were surprised when the decline did not continue. In the 1960s a great many sociologists projected that automation would reduce the average American's work week to less than 25 hours by the century's end. Instead, the average American today is working more hours than in 1968.[8] Paul Ehrlich, in *The Population Bomb,* predicted in the early 1970s that it was already too late to save India from starvation.[9] He did not foresee the tremendous increases in agricultural productivity. Social trends are difficult to anticipate. General forecasting is risky, failure common.

Technological forecasting is no easier. In 1900, few investors forecast that the new automobiles would replace trolley cars.[10] Trolley service had grown tremendously in the previous decade, and it was expanding into long-distance competition with the railroad. The automobile was still a rich man's toy, and no one anticipated the emergence or the tremendous productivity of the automotive assembly line. In the 1930s, when only one in a hundred people had actually been up in an airplane, a majority of Americans mistakenly expected that soon every family would have one.[11] In 1954, Chairman Lewis Strauss of the US Atomic Energy Commission told the National Association of Science Writers that their children would enjoy "electrical energy too cheap to meter."[12] IBM, thinking that mainframes would always be the core of the computer business, waited seven years before competing directly with Digital Computer's minicomputers.[13] Later, Apple mistakenly thought there was a market for its Newton, an early personal digital assistant that had good handwriting recognition but proved too large and too expensive for most consumers. The experts at Microsoft did not foresee the sudden emergence of the World Wide Web, and were slow to compete with Netscape when it appeared. These were all failures of forecasting.

Projection might be expected to work reasonably well when the economy is stable. The total demand for most items will be stable, and extrapolations based on growth rates *may* prove accurate. But a stable market is full of competing products, and full of expanding and contracting firms. In the 1950s, Ford thought there was a market for the Edsel. Furthermore, business conditions are seldom stable for long. In the 1960s, American utility companies expected growth in the consumption of electricity to double every ten years, as it had done for decades. The utility companies did not foresee the energy crises of the 1970s, which would trigger a move toward conservation.[14] The energy crisis likewise caught American automakers unprepared; they had projected continued demand for large cars, and they had few small, energy-efficient vehicles for sale.

As these examples suggest, any trend that seems obvious, and any pattern that seems persistent, may be destabilized by changes in the economy, changes in technology, or some combination of social and technical factors. As the mathematician John Paulos put it, "futurists such as John Naisbitt and Alvin Toffler attempt to 'add up' the causes and effects of countless local stories in order to identify and project trends." But "interactions among the various trends are commonly ignored, and unexpected developments, by definition, are not taken into account. As with weather forecasters, the farther ahead they predict, the less perspicacious they become."[15]

It is not just futurists who stumble. Fundamental innovations almost always seem to come from outside the established market leaders, who suffer from "path dependency." Established firms are usually too committed to a particular conception of what their product is. This commitment is embedded in its manufacturing process and endemic in the thinking of its managers. When a major innovation appears, a leading firm understands the technology, but remains committed to its product and its production system. The case of IBM and the personal computer is a good example. At first IBM did not take the threat seriously enough, and competitors had the market for personal computers to themselves for at least four years before IBM entered the field. IBM then was clever enough to license others to manufacture its system, making it the standard, but it had to share the market with many other firms. In 2005, after 25 years, it withdrew from the market.

In most cases, when an innovation such as the personal computer appears, established industries redouble their commitment to the traditional product that has made them the market leader. They make incremental improvements in manufacturing, and yet they lose market share to the invader. This occurs even in fast-changing electronic industries, where innovations come so frequently that there is little time for routines and habits to blind participants to the advantages of the next change. Utterback cites a comprehensive study of the manufacturers that supply semiconductor firms with photolithographic alignment machines. During the invention and development of five distinct generations of such machines, in no case did the market leader at one stage retain its top position at the next.[16] A production system seems to gain such a powerful hold inside a firm that it seldom can move swiftly enough to adopt innovations.[17]

Another reason that forecasts and predictions are so hard to make is that consumers, not scientists, often discover what is "the next big thing." Most new technologies are market-driven. Viagra was not developed as a sexual stimulant, but the college students who served as guinea pigs discovered what consumers would like about it. This general point can be put negatively: Just because something is technologically feasible, don't expect the public to rush out and buy it. Consumers must want the product. There were many mistaken investments in machines that worked but which the public didn't want. The classic case may be AT&T's Picture Phone.[18] It was technologically feasible, and it was promoted at the New York World's Fair of 1964. But aiming immediately at the mass market, rather than starting more slowly with a niche market, proved a miscalculation. Few bought it, partly because they resisted its high price but also because they feared a visual invasion of their privacy and because they did not understand its potential as a data-display terminal. Though some apparently reasonable technologies fail to sell, people may nonetheless flock to "unreasonable" devices, such as Japanese electronic pets.

Histories of new machines tend to focus on the process of invention and to suggest that the market is driven by research and development. This is usually not so, even in the case of inventions that in retrospect clearly were fundamental to contemporary society: the telegraph, the telephone, the phonograph, the personal computer. When such things first appear, creating demand is more difficult than creating supply. At first, Samuel Morse had trouble convincing anyone to invest in his telegraph. He spent five years "lecturing, lobbying, and negotiating" before he convinced the US Congress to pay for the construction of the first substantial telegraph line, which ran from Washington to Baltimore. Even after it was operating, he had difficulty finding customers interested in using it.[19] Likewise, Alexander Graham Bell could not find an investor to buy his patent on the telephone, and so he reluctantly decided to market it himself.[20] Thomas Edison found few commercial applications for his phonograph, despite the sensational publicity surrounding its discovery.[21] He and his assistants had the following commercial ideas a month after the phonograph was first shown to the world: to make a speaking doll and other toys, to manufacture speaking "clocks . . . to call the hour etc., for advertisements, for calling out directions automatically, delivering lectures, explaining the way," and, almost as an afterthought at the end of the list, "as a musical instrument."[22] In the mid 1970s, a prototype personal computer, when first shown to a group of MIT professors, seemed rather uninteresting to them.[23] They could think of few uses for it, and they suggested that perhaps it would be most useful to shut-ins.

In short, the telegraph, the telephone, the phonograph, and the personal computer, surely four of the most important inventions in the history of communications, were initially understood as curiosities.[24] Their commercial value was not immediately clear. It took both investors and the public time to discover what they could use them for. Eventually large corporations would manufacture each of these inventions, and each became the basis for an international form of communication. As people became familiar with these four technologies, they built them into daily life. Barlow argues that the public's slow response time is generational: ". . . it takes about thirty years for anything really new to arise from an invention, because that's how long it takes for enough of the old and wary to die."[25]

People need time to understand fundamental inventions, which is why they spread slowly; in contrast, innovations are easier to understand and proliferate rapidly. The few fundamental inventions become the bases for entirely new systems, but most innovations plug into an existing system. Once the electrical grid, the telephone network, or the World Wide Web had been built, new application technologies or innovations proliferated. For example, as the electrical grid spread across the United States, small manufacturers rushed in with a stunning array of new products—electrified cigar lighters, model trains, Christmas tree lights, musical toilet-paper dispensers, and shaving cream warmers, as well as toasters, irons, refrigerators, and washing machines. As electric devices proliferated, the large manufacturers Westinghouse and General Electric, like the computer hardware makers of today, soon found it impossible to compete in every area. Once several million PCs and Macs were in place, programmers created the software equivalent of the earlier appliances, with thousands of programs to compose music, calculate income tax, make architectural drawings, encrypt messages, write novels, and so on. Ordinary consumers played a leading role by encouraging such innovations. They drove the rapid growth in sales of scanners, color printers, high-speed modems, external cartridge drives, and software that sends and receives snapshots and short videos.[26]

Selling the basic hardware for a communication system often ceases to be as profitable as selling software and services.[27] People now spend far more money on things that use electricity than on the electricity itself, and this disproportion has been increasing since the 1920s.[28] Something similar happened with the telephone. AT&T began with an absolute monopoly and expanded slowly during the period when no one could compete. During the 1890s, however, AT&T's patent protection ran out, competitors appeared, the market doubled and redoubled in size, and the cost of telephone calls began to drop.[29] The intensity of telephone use and the number of applications was still increasing 100 years later. Where once the telephone bill reflected a simple transaction between a customer and the phone company, now the technology of the telephone is the basis for a wide range of commercial relations that includes toll-free calls to businesses, e-mail, faxes, and SMS messages. Telephones enable people not only to speak to one another, but also to send photographs, texts, news, and videos. As with the electrical system, the telephone provided the infrastructure, or even the main platform, for many unanticipated businesses. The recent proliferation of communication technologies interweaves and connects the electrical grid, the telephone, the television, the personal computer, and the Internet. The synergy of this mix of networked systems makes possible a particularly rich period of innovation. Many possibilities are latent or only partially developed, and that puts a premium on forecasting for the near future.

In this dynamic market, the best design does not always win. Even if someone can accurately foresee the coming of a new technology or an innovation, no one can be certain what design will prove most popular. Perhaps failure was obvious for the air-conditioned bed, the illuminated lawn sprinkler, and the electrically sterilized toilet seat, all marketed in the 1930s,[30] but it was by no means obvious that Sony's Betamax, the technically better machine, would lose out to VHS in the home video market. Marketing, not technological excellence, proved crucial. Sony decided not to share its system with others and expected to reap all the rewards. Its rival, JVC, allied itself with other manufacturers and licensed them to co-produce its VHS system. Consumers decided that more films were likely to be available in the VHS format because a consortium of companies stood behind it, and Betamax gradually lost out.[31] Perhaps the most familiar recent example of a superior machine capturing only a small part of the market is that of Apple's Macintosh computers. Here again a decision to "go it alone" appears to have been a decisive mistake.[32] A somewhat different example is the case of FM radio, which is better for short-distance transmission than AM. It languished virtually unused for a generation because RCA discouraged its use while promoting its already well-established AM network.[33]

Consider an example from the electrical industry: district heating vs. individual home heating. A hundred years ago, most power stations were near town centers, and they routinely marketed excess steam for the heating of apartment blocks, office buildings, and department stores. Since then district heating has failed to capture much of the American market,[34] although in Scandinavia district heating is popular because it saves energy, lowers pollution levels, and reduces the cost of home heating. District heating was also widespread and apparently worked well in the former Soviet Union, but the plants are now often shut down for "cleaning," especially during the summer, leaving apartments without hot water. American social values emphasize individualized technologies. Every house has its own heating system, even though this is a wasteful and inefficient choice. If the market to some extent shapes technologies, the market in turn is inflected by cultural values.

Even if one can predict which new technologies are possible and forecast which designs will thrive in the market, people may fail to foresee how they will be used. Edison invented the phonograph, but he thought his invention primarily would aid businessmen, who could use it to dictate letters, and he did not focus on music and entertainment even as late as 1890.[35] As a result, competitors grabbed a considerable share of the market, and their system of a flat record on a turntable won out over his turning cylinders. Another example: Between 1900 and 1920 the new technology of radio was perceived by government and industry as an improved telegraph that needed no wires. They expected it to be used for point-to-point communications. When radio stations emerged after World War I as consumer-driven phenomena, the electrical corporations were caught off guard, but they quickly moved into the new market.[36] The public used both the phonograph and the radio less for work than for fun.[37] Likewise, many children use personal computers less to write papers and pursue education than to play computer games and visit strange websites. These activities may or may not be educational; my point is that they were unanticipated and consumer driven.

Another example of unanticipated use is the higher-than-expected consumption of electricity by refrigerators, which so puzzled a California utility company that it hired anthropologists to find out what was going on.[38] They discovered that families used the refrigerator for much more than food storage. It was also a place to hide money in fake cabbages, to protect photographic film, to give nylon stockings longer life, to allow pet snakes to hibernate, and to preserve drugs. At times people opened the refrigerator and gazed in without clear intentions, mentally foraging, trying to decide if they were hungry, often removing nothing before they closed the door again. The anthropologists concluded that the refrigerator, and by extension any tool, "enters into the determination of its own utilities, suggesting new ideas for its own definition . . . and . . . threatens to take on altogether new identities. . . ." The Internet offers a final, stunning example of this principle. Only military planners and scientists initially used this communication system. They developed a decentralized design so that messages could not easily be knocked out by power failures, downed computers, or a war. But this same feature made it difficult to monitor and control the Internet. The developers did not imagine such things as Amazon.com, pornography on the net, downloading digitized music to a personal computer, or most of the other things people today use the Internet for. In short, when we review the history of the phonograph, the radio, the refrigerator, and the Internet, technologies conceived for one clearly defined use have acquired other, unexpected uses over time. Engineers and designers tend to think new devices will serve a narrow range of functions, while the public has a wide range of intentions and desires and usually brings far more imagination to new technologies than those who first market them.

Furthermore, a technology's symbolic meanings may determine its uses. Too often we think of technologies in purely functional terms. However, even so prosaic a device as the electric light bulb had powerful symbolic meanings and associations at its inception. Edison's practical incandescent light of 1879 was preceded by many forms of "impractical" electric lighting in theaters, where it was used for dramatic effects. A generation before Edison's light bulb even began to reach most homes (after 1910), it was appropriated by the wealthy for conspicuous consumption, used to illuminate public monuments and skyscrapers, and put into electrical signs. As a result, by 1903 American cities were far more brightly lighted than their European counterparts: Chicago, New York, and Boston had three to five times as many electric lights per inhabitant as Paris, London, or Berlin.[39] Intensive electric lighting of American downtowns far exceeded the requirements of safety. The Great White Way and its huge signs had become a national landmark by 1910, and postcards and photographs of illuminated city skylines became common across the United States. In New York, during World War I when wartime energy saving darkened Times Square, the citizens complained that the city seemed "unnatural." People demanded that the giant advertising signs be turned on again, and they soon were, with new slogans selling war bonds.[40]

This intensive use of lighting in the United States was in no sense a necessity, and the European preference for less electric advertising was not temporary or the expression of a "cultural lag." Many European communities still resist electric signs and spectacular advertising displays. At the 1994 Winter Olympics in Norway, the city council of Lillehammer refused Coca-Cola and other sponsors the right to erect illuminated signs. On the city's streets only wooden and metal signs were permitted. No neon or transparent plastic was allowed. Levels and methods of lighting vary from culture to culture, and what is considered normal or necessary in the United States may seem to be a violation of tradition elsewhere.[41]

The preceding survey shows that, far from being deterministic, technologies are unpredictable. A fundamentally new invention often has no immediate impact; people need time to find out how they want to use it. Indeed, the best technologies at times fail to win acceptance. Furthermore, the meanings and uses people give to technologies are often unexpected and non-utilitarian. Economics does not always explain what is selected, how it is used, or what it means. From their inception, technologies have symbolic meanings and non-utilitarian attractions.

A technology is not merely a system of machines with certain functions; rather, it is an expression of a social world. Electricity, the telephone, radio, television, the computer, and the Internet are not implacable forces moving through history, but social processes that vary from one time period to another and from one culture to another. These technologies were not "things" that came from outside society and had an "impact"; rather, each was an internal development shaped by its social context. No technology exists in isolation. Each is an open-ended set of problems and possibilities. Each technology is an extension of human lives: someone makes it, someone owns it, some oppose it, many use it, and all interpret it. Because of the multiplicity of actors, the meanings of technology are diverse. This insight is useful for considering how historians understand technology (chapter 4) and for looking into the relationship between technology and cultural diversity (chapter 5).

4 How Do Historians Understand Technology?

The previous two chapters suggest that one must reject technological determinism and admit that the invention and the diffusion of technologies are not predictable. What is the alternative? Historians in the field give roughly equal weight to technical, social, economic, and political factors. Their case studies suggest that artifacts emerge as the expressions of social forces, personal needs, technical limits, markets, and political considerations. They often find that both the meanings and the design of an artifact are flexible, varying from one culture to another, and from one time period to another. Indeed, Henry Petroski, one of the most widely read experts on design, argues that there is no such thing as perfect form: "Designing anything, from a fence to a factory, involves satisfying constraints, making choices, containing costs, and accepting compromises."[1] Technologies are social constructions. Historians of technology have also generally agreed that after initial invention comes an equally important stage of "development." Indeed, since the late 1960s the study of development has been at the center of much work in the field, for example in studies of Nicholas Otto's internal-combustion engine or the development of the diesel engine.[2] Nathan Rosenberg, a leading economic historian, emphasizes that for every new product or production technique "there is a long adjustment process during which the invention is improved, bugs ironed out, the technique modified to suit the specific needs of users, and the 'tooling up' and numerous adaptations made so that the new product (process) can not only be produced but can be produced at low cost." Indeed, during this "shakedown period" of early production some feasible inventions are abandoned as unprofitable.[3] As the study of development has increased, the heroic "lone inventor" has largely disappeared from scholarship. Anthony F. C. Wallace, a senior historian in the field, declared: "We shall view technology as a social product and shall not be over much interested in the priority claims of individual inventors, for the actual course of work that leads to the conception and use of new technology *always* involves a group that has worked for a considerable period of time on the basic idea before success is achieved."[4]

Variation in design continues during early stages of development, until one design meets with wide approval. Once a particular design is widely accepted, however, variation in form gives way to innovation in production. Take the bicycle as an example. The earliest bicycles (high-wheelers) were handmade and cost an ordinary worker a year's wages. Only the well-to-do could afford them. Most riders were young and male. The danger of toppling from a high-wheeler gave bicycling a macho aura. For more than a generation, low-wheel bikes were for women, clergymen, and old people. Tremendous experimentation took place as inventors changed the size of the wheels, made three-wheelers, moved the larger wheel from the front to the back, and tried out various materials, including wood and steel frames. They developed different drive and braking systems, tried various shapes and positions for the handlebars, and created accessories such as lights and panniers. Dunlop developed air-filled rubber tires that together with a padded seat reduced discomfort from bumps and vibrations. At first, professional racers derided these "balloon" tires as being for sissies. However, bicycle design reached closure in the 1890s, when low-wheel models with front and back wheels of equal size and fitted with Dunlop tires proved to be the fastest on the racetrack.

Once the low-wheel "safety bicycle" had become accepted as the standard, manufacturing changed. The leading producers of high-wheelers, such as the Pope Company, had prided themselves on durable construction by skilled artisans, who adjusted the wheel size of each cycle to match the length of a customer' legs. In the 1880s such bicycles cost $300 or more, well beyond the reach of the average consumer. In the 1890s, however, mass producers such as Schwinn made bicycles with stamped and welded frames. They were of lesser quality, but priced as low as $50. By 1910 a used bicycle in working order could be had for $15, and ownership had spread to all segments of society. The bicycle had ceased to be a toy for the wealthy and had become a common form of transportation and recreation for millions. The military had adapted it to troop transport, delivery services had thousands of bicycle messenger boys, and bicycle racing had emerged as a professional sport.

The social significance and use of the bicycle was not technologically determined. For example, from the beginning some women adopted the bicycle, and during the era of the high-wheeler some joined the popular bicycle clubs. In 1888, eighteen women were members of a Philadelphia club, and one of them won the "Captain's Cup," awarded annually to the member who covered the most miles (in this case, 3,304¼). However, women on wheels met opposition. Some physicians declared that the bicycle promoted immodesty in women and harmed their reproductive organs. Moralists thought women on bicycles were indecent because they wore shorter skirts to ride them, and worried that women would find straddling the seat sexually stimulating. The bicycle craze helped kill the bustle and the corset and encouraged "common-sense dressing." Many in the women's suffrage movement adopted bicycles. In 1896, Susan B. Anthony declared: "Bicycling . . . has done more to emancipate women than anything else in the world. I stand and rejoice every time I see a woman ride by on a wheel. It gives women a feeling of freedom and self-reliance."[5] The women's movement embraced the bicycle, and its democratization became part of their drive for social equality.

Outside the United States, the bicycle persisted much longer as an important form of transportation. In the Netherlands and in Denmark, bicycles were more common than automobiles were until the early 1960s. In those countries, major roads have special lanes and special traffic signals for bicyclists, and government programs encourage citizens to use bicycles instead of automobiles. But most Western societies have chosen the automobile as the primary mode of transportation instead, and even in Denmark and the Netherlands bicyclists are not as numerous as they were a generation ago. Despite the bicycle's head start on the automobile, in most societies only the automobile seemed to achieve what Thomas Hughes calls "technological momentum."

Hughes argues that technical systems are not infinitely malleable. If technologies such as the bicycle or the automobile are not independent forces shaping history, they can still exercise a "soft determinism" once they are in place. "Technological momentum" is a particularly useful concept for understanding large-scale systems, such as the electric grid, the railway, or the automobile. In *Networks of Power,* Hughes examines five stages of system development for the electrical grid, and these stages can apply to other inventions as well. In the case of electrification, the sequence began in the 1870s with invention and early development in a few locations (1875–1882). That was followed by technology transfer to other regions (1882–1890). With successful transfer came growth (1890–) and the development of subsidiary infrastructures of production, education, and consumption, leading to technological momentum (after c. 1900) as electricity became a standard source of light, heat, and power. In the mature stage (after. c. 1910), the problems faced by management required financiers and consulting engineers.[6]

"Technological momentum" is not inherent in any technological system when first deployed. It arises as a consequence of early development and successful entrepreneurship, and it emerges at the culmination of a period of growth. The bicycle had such momentum in Denmark and the Netherlands from 1920 until the 1960s, with the result that a system of paved trails and cycling lanes were embedded in the infrastructure before the automobile achieved momentum. In the United States, the automobile became the center of a socio-technical system more quickly and achieved momentum a generation earlier. Only some systems achieve "technological momentum," which Hughes has also applied to analysis of nitrogen fixation systems and atomic energy.[7] The concept seems particularly useful for understanding large systems. These have some flexibility when being defined in their initial phases. But as technical specifications are established and widely adopted, and as a system comes to employ a bureaucracy and thousands of workers, it becomes less responsive to outside pressures. Hughes provided an example in *American Genesis:* ". . . the inertia of the system producing explosives for nuclear weapons arises from the involvement of numerous military, industrial, university, and other organizations, as well as from the commitment of hundreds of thousands of persons whose skills and employment are dependent on the system."[8] Similarly, at the end of the nineteenth century, once the width of railway tracks had been made uniform and several thousand miles were laid out, once bridges and grade crossings were designed with rail cars of certain dimensions in mind, it was expensive and impractical to reconfigure a railway system.

Hughes makes clear when discussing "inertia" that the concept is not only technical but also cultural and institutional. A society may choose to adopt either direct current or alternating current, or to use 110 volts, or 220 volts, or some other voltage, but a generation after these choices have been made it is costly and difficult to undo such a decision. Hundreds of appliance makers, thousands of electricians, and millions of homeowners have made a financial commitment to these technical standards. Furthermore, people become accustomed to particular standards and soon begin to regard them as natural. Once built, an electrical grid is "less shaped by and more the shaper of its environment."[9] This may sound deterministic, but it is not entirely so, for people decided to build the grid and selected its specifications and components. To later generations, however, such technical systems seem to be deterministic.[10]

The US electrical system achieved technological momentum around 1900. By that time, it was "reinforced with a cultural context, and interacting in a systematic way with the elements of that context," and "like high momentum matter [it] tended in time to resist changes in the direction of its development."[11] From 1900 on, growth was relentless and not easily deflected by contingencies. The electrical system was far more than machines themselves; it included utility companies, research laboratories, regulatory agencies, and educational institutions, constituting what Hughes calls a "sociotechnical system." It had high momentum, force, and direction because of its "institutionally structured nature, heavy capital investments, supportive legislation, and the commitment of know-how and experience."[12] Similarly, the automobile achieved technological momentum not as an isolated machine, but as part of a system that included road building, driver education programs, gas stations, repair shops, manufacturers of spare parts, and new forms of land use that spread out the population into suburbs that, practically speaking, were accessible only to cars and trucks.

The concept of technological momentum provides a way to understand how large systems exercise a "soft determinism" once they are in place. Once a society chooses the automobile (rather than the bicycle supplemented by mass transit) as its preferred system of urban transportation, it is difficult to undo such a decision. The technological momentum of a system is not simply a matter of expense, although the cost of building highways, bicycle lanes, or railroad tracks is important. Ultimately, the momentum of a society's transport system is embodied in the different kinds of cities and suburbs fostered by each form of transportation. Relying on bicycles and streetcars has kept Amsterdam densely populated, which in turn means that relatively few kilometers of streetcar line can efficiently serve the population. If the Dutch were to decide to rely more on the automobile, they would have to rip apart a tightly woven urban fabric of row houses, canals, and small businesses. In contrast, cities such as Houston, Phoenix, and Los Angeles sprawl over larger areas, with more than half the land area devoted to roads, parking lots, garages, gas stations, and other spaces for automobiles. Such a commitment to the automobile has resulted in massive infrastructure investments that make it impractically expensive to shift to mass transit, not least because the houses are so far apart. In the United States the automobile now is "less shaped by and more the shaper of its environment."[13] Hughes's idea of "technological momentum" is far less deterministic than externalist theories, and provides a useful way to think about how large socio-technical systems operate in society.

Most historians of technology are either contextualists or internalists.[14] These are not so much opposed schools of thought as different emphases. Internalists reconstruct the history of machines and processes focusing on the role of the inventor, laboratory practices, and the state of scientific knowledge at a particular time. They chart the sequence that leads from one physical object to the next. The internalist approach has some affinities with art history,[15] but it grew out of the history of science. A five-volume *History of Technology* published in the 1950s detailed the histories of industrial chemicals, textile machinery, steelmaking, electric lighting and generating systems, and so forth.[16] Internalists establish a bedrock of facts about individual inventors, their competition, their technical difficulties, and their solutions to particular problems.

An internalist may be a feminist working on Madame Curie or a railroad historian interested in how different kinds of boxcars developed. Tracy Kidder's best-selling book *The Soul of a New Machine* is an example.[17] Kidder spent months observing a team that was inventing a new computer, charting the work process, the pressures from management for rapid results, the continual advances in electronics that made it hard to know when to freeze the design of the machine, and the step-by-step developments that led to a final product. The book ends shortly after the company presents the new computer to the public at a press conference. It does not examine the consumer's response to the computer or tell the reader much about its sales success. The internalist writes from the point of view of an insider who looks over an inventor's shoulder. Such studies, whether of the light bulb, the computer, or the atom bomb, culminate at the moment when the new device is ready for use.

If many non-specialists believe that necessity is the mother of invention, internalists usually find that creativity is by no means assured or automatic. A machine that society fervently desires cannot be ordered like a pizza. Edison spent years trying to invent a lightweight battery for electric automobiles that could be recharged quickly and could hold a charge for a long time. He made some progress, but 100 years later the problem still eludes complete solution.[18] Money and talent can speed refinements along, but they cannot always call an invention into being.

The internalist approach also emphasizes alternative solutions to problems. For example, late in the nineteenth century the need for flexible power transmission over a distance was solved by a variety of devices. In different places one could buy power in the form of compressed air, pressurized water, moving cables, steam, and electricity. These were not merely invented: by 1880 all were in commercial use. In Paris, compressed air drove machines in some small businesses. It was easy to use and far less trouble than installing and maintaining a steam engine. In New York and other nearby cities, the hot-air engine enjoyed a brief vogue. In Boston, from 1880 until as late as 1962 many small businesses in a single block had steam power delivered to them by overhead driveshafts. In hilly San Francisco, cable cars were superior to streetcars driven by electric motors.[19] The research of internalist historians explains the precise characteristics of these power systems, helps us to understand their relative merits, and shows us how they were used and why they were eventually abandoned.

The internalist can compare the technical merits of early steam-powered, electric-powered, and gasoline-powered automobiles, all of which were successfully produced and marketed between 1900 and 1920. This is necessary (but not sufficient) knowledge to understand why Americans preferred gasoline automobiles, even though initially they were more familiar with the steam engine. Only in retrospect was the gasoline engine the obvious winner. In 1900 the majority of the roughly 8,000 automobiles in the United States were steam-powered; gasoline autos were the least common type.[20] The electric car was the quietest and least polluting of the three, but it lacked the range of the others. Steam automobiles took the longest to start, as it took time to get cold water up to a boil. The Stanley Steamer overcame this objection by heating water in small amounts as it was needed. The steam auto was reliable, and people understood its technology.

Internal-combustion engines were noisy and polluting. Furthermore, there were few filling stations or mechanics to service them in 1900, while steamers burned kerosene, which was available in any hardware store. In addition, the early gasoline autos had to be cranked, which was inconvenient, physically demanding, and somewhat dangerous—the crank could kick back and hurt one's wrist or arm. On the other hand, because the steam auto was the heaviest of the three types, it was hard on driveways and road surfaces, and, at a time when most roads were unpaved, it easily got stuck in the mud. The batteries for electric cars were heavy and took a long time to recharge, making long trips inconvenient. The internal-combustion engine delivered the most power for its weight because its fuel had a high energy density. The internalist approach thus can identify the strengths and weaknesses of competing technologies. Clearly, the gasoline auto's longer range, lighter construction, and greater power gave it decided advantages. Yet such factors alone did not give it what Hughes would call technological momentum. By c. 1905 all three forms of automobile had been invented, had begun to spread into the society, and had experienced growth in demand. But none had gained a decisive lead, and all still competed with streetcars and bicycles.

To tell the story beyond this point requires the contextualist approach, which focuses on how the larger society shapes and chooses machines.[21] It is impossible to separate technical and cultural factors when accounting for which technology wins the largest market share. The Stanley brothers made fine steam cars, but, like most automakers, they built them by hand and in limited numbers. This meant that they were priced high. Electrics were manufactured in much the same way, so they had no price advantage. Some electrics were marketed as ideal for women, however. A sales strategy that "feminized" their ease in starting, lower speed, and limited range made such cars unappealing to men without attracting many female buyers.[22] Only the gasoline auto had an entrepreneur of the caliber of Henry Ford, who realized that the way forward was mass production of a standard design at the lowest possible price. As his managers invented and installed the assembly line, they brought the price of a new car down from more than $850 in 1908 to $360 in 1916.[23] Ford also benefited from geographical factors. The gasoline auto was best suited to use in the countryside, where the heavier steam cars sank into the mud and electrics could seldom be recharged. (Only one farmer in 15 had electricity.) In 1910 more than half the population of the United States remained on the land, and the gasoline auto had that market virtually to itself. Furthermore, rural people could better afford the Model T than its hand-assembled and more expensive competition. By 1926 an astonishing 90 percent of the farmers in Iowa owned automobiles,[24] and Ford had sold almost 15 million Model Ts. Ford's success spurred subsidiary investment in service stations, the training of thousands of mechanics, and the creation of a national network of companies selling tires, batteries, spare parts and the automobiles themselves. By the end of the 1920s, an auto industry overwhelmingly devoted to the internal-combustion engine consumed 20 percent of the nation's steel, 80 percent of its rubber, and 75 percent of its plate glass. Embedded in this extensive socio-technical system, the gasoline auto had achieved a technological momentum in the United States that it would not attain in Europe until the 1950s. In 1926, 78 percent of the world's automobiles were in North America. There was one for every six Americans, but only one for every 102 Germans.[25]

The success of the gasoline automobile can thus be attributed to a variety of interlinked factors. The lack of an electrical grid in large parts of the country and the unresolved problem of the heavy, slow-charging battery counted against the electric car, as did its extensive marketing as a woman's vehicle. The steam car had none of these problems, and the steam engine was familiar. Yet the steam car was the heaviest, it was not manufactured as cheaply or marketed as aggressively as the gasoline car, and gasoline was abundant and inexpensive. Thus, a wide range of factors were involved, including economics, entrepreneurship, and social norms as well as technology. In thinking about why AT&T's picture phone failed in the 1970s, Kenneth Lepartito concluded that any technology should be understood not as an isolated thing in itself, but as part of a complex system "in which machines have ramifications for other machines, for the plans of contending actors, and for politics and culture." Therefore, "all technological change becomes problematic. This indeterminacy flows from the fact that technology is not a stable artifact but a system in evolution, one whose features and functions are up for grabs."[26] But if a technology is widely adopted, this indeterminacy gives way to momentum.

In the contextual approach, every technology is deeply embedded in a continual (re)construction of the world. A contextualist eschews the Olympian perspective and tries to understand technologies from the point of view of those who encountered them in a particular time and place. This approach immediately implies that machines and technical processes are parts of cultural practices that may develop in more than one way. For example, the contextualist sees the computer not as an implacable force moving through history (an externalist argument), but as a system of machines and social practices that varies from one time period to another and from one culture to another. In the United States, the computer was not a "thing" that came from outside society and had an "impact"; rather, it was shaped by its social context. In this perspective, each technology is an extension of human lives.

The same generalizations apply to the Internet. Civilians under contract with the Department of Defense developed the Internet to facilitate communication among scientists using the large computers located at universities around the United States. The military funded it and understood its possible use in transmitting vital defense information in case of atomic attack. But the first working system connected universities, and when it was put into operation there was not a great deal of traffic.[27] No one had anticipated the most popular application: what we now call e-mail. In its early years, the system was funded by the Advanced Research Project Agency, out of the Pentagon, and was called ARPANET. In the 1970s, once it was up and running, the military tried to sell the system to AT&T, but AT&T refused the offer. For the next 15 years, scientists and grassroots organizations developed e-mail, user groups, and databases on the net.[28] In the 1990s came the World Wide Web, web browsers, and e-commerce. Then in a great rush the Internet became an integral part of advertising, marketing, politics, news, and entertainment. People used the Internet in unexpected and sometimes illegal ways. For some, "surfing" became a kind of tourism and an entertainment that partly replaced television. For others, the Internet offered ways to share music (often pirated), or to publish their thoughts and ideas in "blogs" (short for "weblogs") addressed to the world. The popular acceptance of the Internet raised political issues. Who should own and control it? Did it threaten to destroy jobs by eliminating middlemen, or was it the basis of a new prosperity? Did it democratize access to information, or did it create a "digital divide" between those who could afford it and those who could not? Like every technology, the Internet implied new businesses, opened new social agendas, and raised political questions. It was not a thing in isolation.

If one takes this approach, then it appears fundamentally mistaken to think of "the home" or "the factory" or "the city" as a passive, solid object that undergoes an involuntary transformation when a new technology appears. Rather, every institution is a social space that incorporates or doesn't incorporate the Internet at a certain historical juncture as part of its ongoing development. The Internet offers a series of choices based only partly on technical considerations. Its meaning must be looked for in the many contexts in which people decide how to use it. For example, in the 1990s many chose to buy books, videos, and CDs on the Internet, but not all were ready for the online purchase of groceries. By 2004 British supermarkets had wooed many customers to shop online for food, but the same idea had little success in Denmark, even though a higher percentage of Danes were online. People in many countries preferred the Internet to the fax machine, but use of the telephone continued to expand. People adapted the Internet to a wide range of social, political, economic, and aesthetic contexts, weaving it into the fabric of experience. It facilitated social transformations, but different societies incorporated it into the structures of daily life in somewhat different ways. Every culture continues to make choices about what to do with this new technology.

The history of electrification offers a suggestive parallel to the Internet. Between c. 1880 and 1920, when the electrical system was being built into American society, a lively debate took place among engineers, progressive reformers, businessmen, and the general public. This debate about the cultural meaning and uses of electricity was necessary because Americans of c. 1900 had to choose whether to construct many small generating stations or a centralized system, whether to adopt alternating or direct current, whether to rely on public or private ownership of the system, and whether to give control primarily to technicians, to capitalists, or to politicians. Similarly, the debate about the Internet (after c. 1992) was necessary because people had to decide whether to construct a decentralized or a centralized system. They debated to what extent it should be monitored or controlled by individuals, corporations, or the government, and they questioned to what degree the Internet and its many individual sites and homepages should become commercialized. Finally, they wrestled with the issue of proprietary software, shareware, and freeware, and with related issues of copyright and intellectual property.

Like the collaborative building of the Internet, electrification was not a "natural process" but a social construction that varied from country to country. For example, electrical light and power were embraced readily by the working class in Sweden, where the first educational publication of the Social Democrats (1897) was titled *Mere Ljus* (meaning "more light").[29] In contrast, South African mining towns used electricity almost exclusively to improve the extraction of gold, diamonds, and coal, and seldom to enhance the lives of black workers.[30] Yet not all consumers immediately embraced electricity. The majority of British workers long retained a familiar gas system. As late as 1936, only one-third of the dwellings in the industrial city of Manchester had electricity.[31] In the United States electrification proceeded much more rapidly, and more than 90 percent of urban homes had electricity in 1936.[32] Just as in the 1990s a divide opened between those who had computers and Internet connections and those who did not, during the 1930s there were equally worrisome divisions between those who had electricity and those who did not. The construction of the Internet opened up political issues, legal problems, entertainment possibilities, and business opportunities. As with electricity, the public found the Internet to be suddenly ubiquitous and yet inscrutable, and it often seemed to be an irresistible natural force. And as with electricity in 1910, so much was attributed to the Internet in the 1990s that it became a universal icon of the age.

The histories of the bicycle, the automobile, electrification, and the Internet all suggest, once again, that there is little basis for a belief in technological determinism. Sweeping externalist histories about machines that shape society remain popular, but they clash with the research of most professional historians of technology (both internalists and contextualists). The more one knows about a particular device, the less inevitable it seems. Yet a thousand habits of thought, repeated in the press and in popular speech, encourage us in the delusion that technology has a will of its own and shapes us to its ends.

As we become accustomed to new things, they are woven into the fabric of daily life. Gradually, every new technology seems to become "natural," and therefore somehow "inevitable" because it is hard to imagine a world without it. Through most of history flush toilets did not exist, but after 100 years of widespread use they seem normal and natural; the once-familiar outhouse now seems disgusting and unacceptable. Likewise, Western societies have naturalized the radio, the mobile phone, and the television, and most people do not think of them as social constructions.

The novelist Richard Powers noted that the naturalization of technology involves the continual transformation of human desires "until in a short time consumers cannot do without a good that did not exist a few years before." As a contrast, Powers describes a character who has escaped from this continual process of naturalizing the new. She does not transform her apartment to accord with changing fashions, but keeps whatever she likes, regardless or style or age: ". . . Mrs. Shrenck's thing-hoard implied that she had bypassed this assimilation altogether, simply by making no distinction in value between a pine-cone picked up on yesterday's walk and a rare, ancient floor-cabinet radio. . . ."[33] Few consumers are so indifferent to style, however. And once one sees that technologies are shaped by consumption, it becomes apparent that, though devices change often, they do not necessarily improve. One of mankind's oldest technologies, clothing, offers a fine example, for stylistic considerations have often proved more important than comfort or durability. Judith McGaw examined the enormous variety of brassieres and found not only that there is “no convincing evidence that the breasts need support” but also that brassieres never quite fit. Women do not come in standard sizes, and furthermore “the size and shape of any woman’s breasts change continuously—as she ages, as she gains or loses weight, as she goes through pregnancies, as she experiences her monthly hormonal cycles.”[34] In selecting bras and other clothing, women continuously compromise between style, comfort, and self-expression. As this example suggests, the human relationship to technology is not a matter of determinism; it is unavoidably bound up with consumption.